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SOUTH ASIA REGIONAL INITIATIVE FOR ENERGY COOPERATION AND DEVELOPMENT (SARI-Energy)

Wind Resource Assessment and Mapping for Afghanistan and Pakistan

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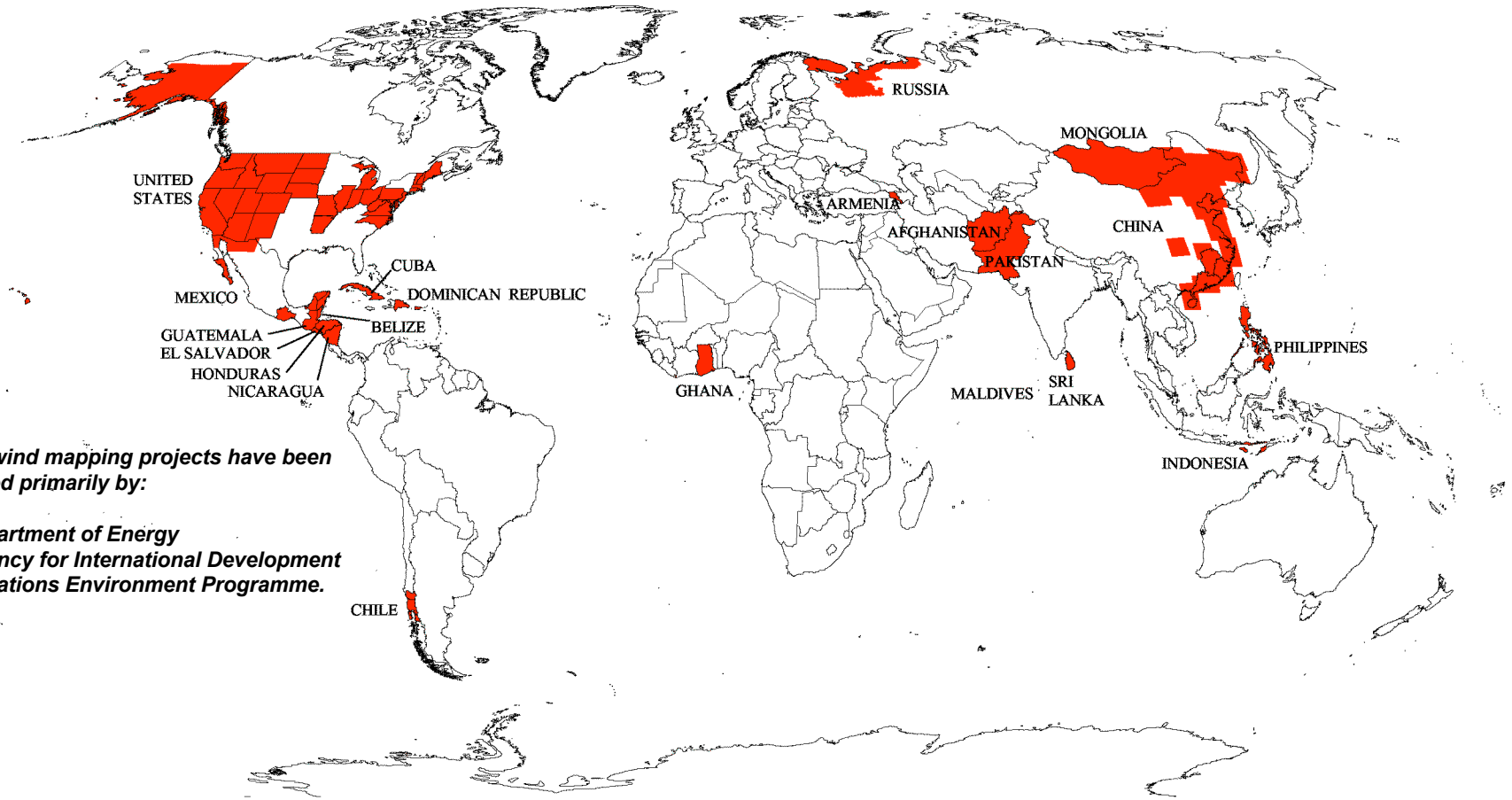
Benefits of Detailed, Regional Wind Mapping

- Accelerate identification of promising areas for wind prospecting and project development
- Facilitate investment in large-scale wind energy projects
- Support informed decision-making by public and private sectors
- Accelerate the wind project deployment process

NREL's High-Resolution Wind Mapping Approach

- Computerized mapping approach using Geographical Information System (GIS) software (ArcInfo® and ArcView®)
- Designed for regional wind mapping (not micrositing)
- Combination of numerical, empirical and analytical methods
- Does not depend on high-quality surface wind data (but it helps)
- Produces 1 km^2 or finer wind power maps

NREL's High Resolution Wind Mapping and Validation Projects



NREL's wind mapping projects have been supported primarily by:

U.S. Department of Energy
U.S. Agency for International Development
United Nations Environment Programme.

High-resolution (1 km^2 or finer) regional or national wind resource maps have been produced or are in progress for:

- Afghanistan
- Armenia
- Belize
- Chile - specific areas
- China - specific areas
- Cuba
- Dominican Republic
- El Salvador
- Ghana
- Guatemala
- Honduras
- Indonesia - specific areas
- Maldives
- Mexico - specific areas
- Mongolia
- Nicaragua
- Pakistan
- Philippines
- Russia - specific areas
- Sri Lanka
- United States - specific areas

U.S. Department of Energy
National Renewable Energy Laboratory

NREL

31-OCT-2006 3.7.1

Afghanistan and Pakistan Wind Mapping Project Responsibilities

- NREL
  - project coordination
  - data collection and analysis
  - review and validation of preliminary wind maps from numerical modeling
  - final map development and resource characterization
  - documentation
- 3TIER Environmental Forecast Group (subcontractor to NREL)
  - numerical modeling to produce preliminary wind map estimates
- Country Organizations
  - collection of data from in-country sources
  - data sent to NREL for review and use in the assessment

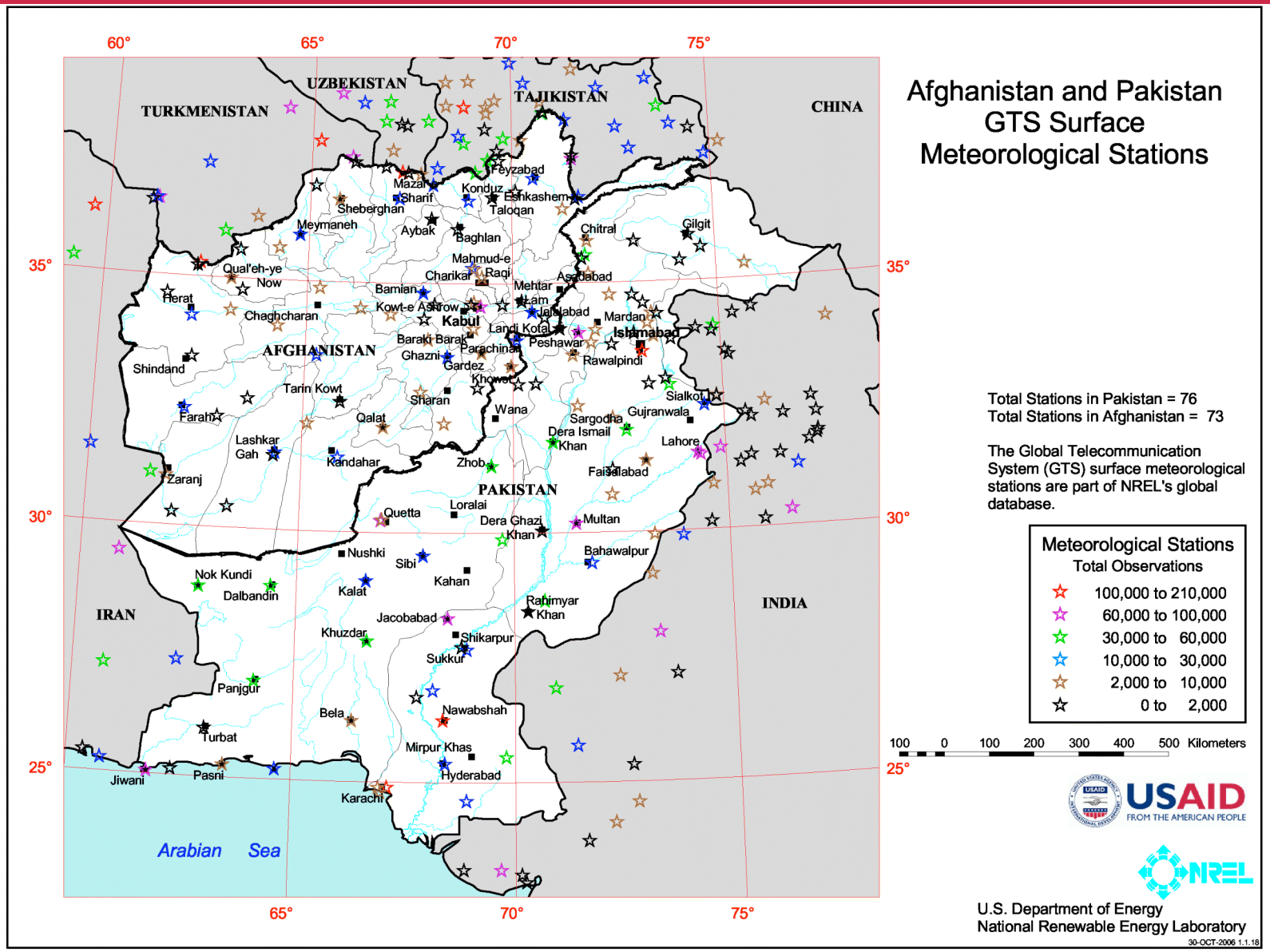
Major Global Data Sets used by NREL for Wind Resource Assessment

Data Set	Type of Information	Source	Period of Record
Surface Station Data	Surface observations more than 20000 stations	NOAA/NCDC	Variable up to 2006
Upper Air Station Data	Rawinsonde and pibal observations at 1800 stations	NCAR	1973-2005
Satellite -derived Ocean Wind Data	10-m ocean wind speeds gridded to 0.25 deg	NASA/JPL	1988-2006
Marine Climatic Atlas of the World	Gridded (1.0 deg) statistics of historical ship wind observations	NOAA/NCDC	1854-1969
Reanalysis Upper Air Data	Model -derived gridde d (~200km) upper air data	NCAR	1958-2005
Global Upper Air Climatic Atlas	Model -derived gridded (2.5 deg) upper air statistics	NOAA/NCDC	1980-1991
Digital Geographic Data	Political, hydrography, etc.	ESRI	
Digital Terrain Data	Elevation – 1 km resolut ion	USGS/EROS	
Digital Land Cover Data	Land use/cover and tree cover density – 0.5 km resolution	NASA/USGS	

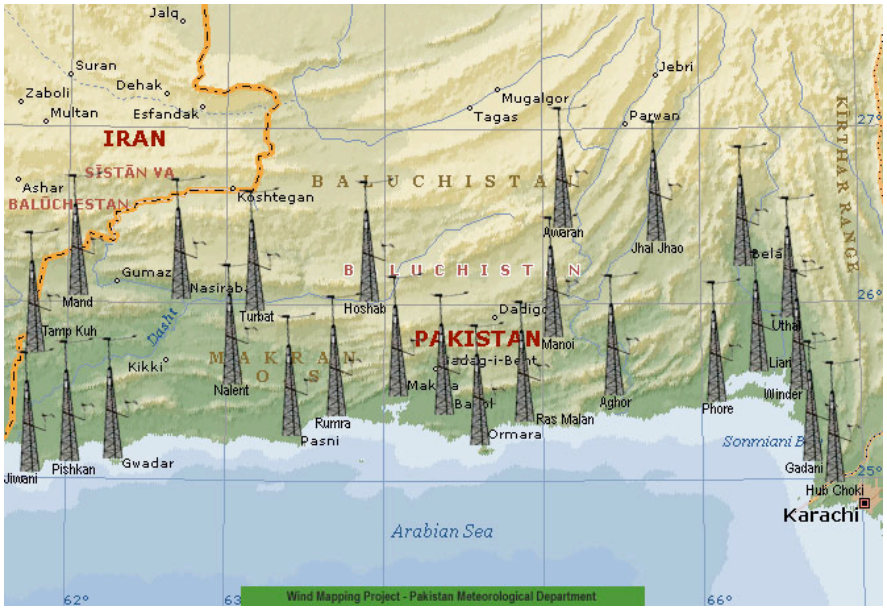
Numerical Modeling Method
Afghanistan and Pakistan Wind Mapping

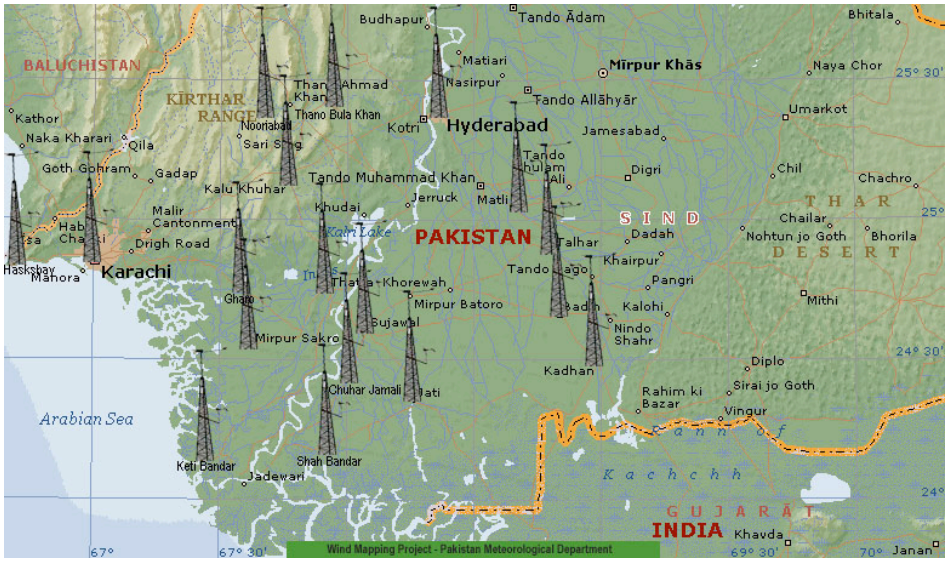
- Model Design and Outputs
  - Modeling system created by 3TIER (U.S. company based in Seattle, WA)
  - A numerical weather model (WRF) coupled to a wind flow model (CALMET) and global weather, topographical, and land cover data
  - NCEP/NCAR Reanalysis (200-km grid) - most important global weather input for WRF
  - WRF simulates weather conditions (including winds) over 365 days selected from a 15-year period
  - WRF simulations to 2.5 km and CALMET simulations to 1 km
  - Model output grids provided to NREL for review and improvement with empirical and analytical methods

Data Analysis for Assessment and Validation –
Surface, Upper-Air, Reanalysis, and Satellite Ocean Data



Recent Wind Measurements in Pakistan

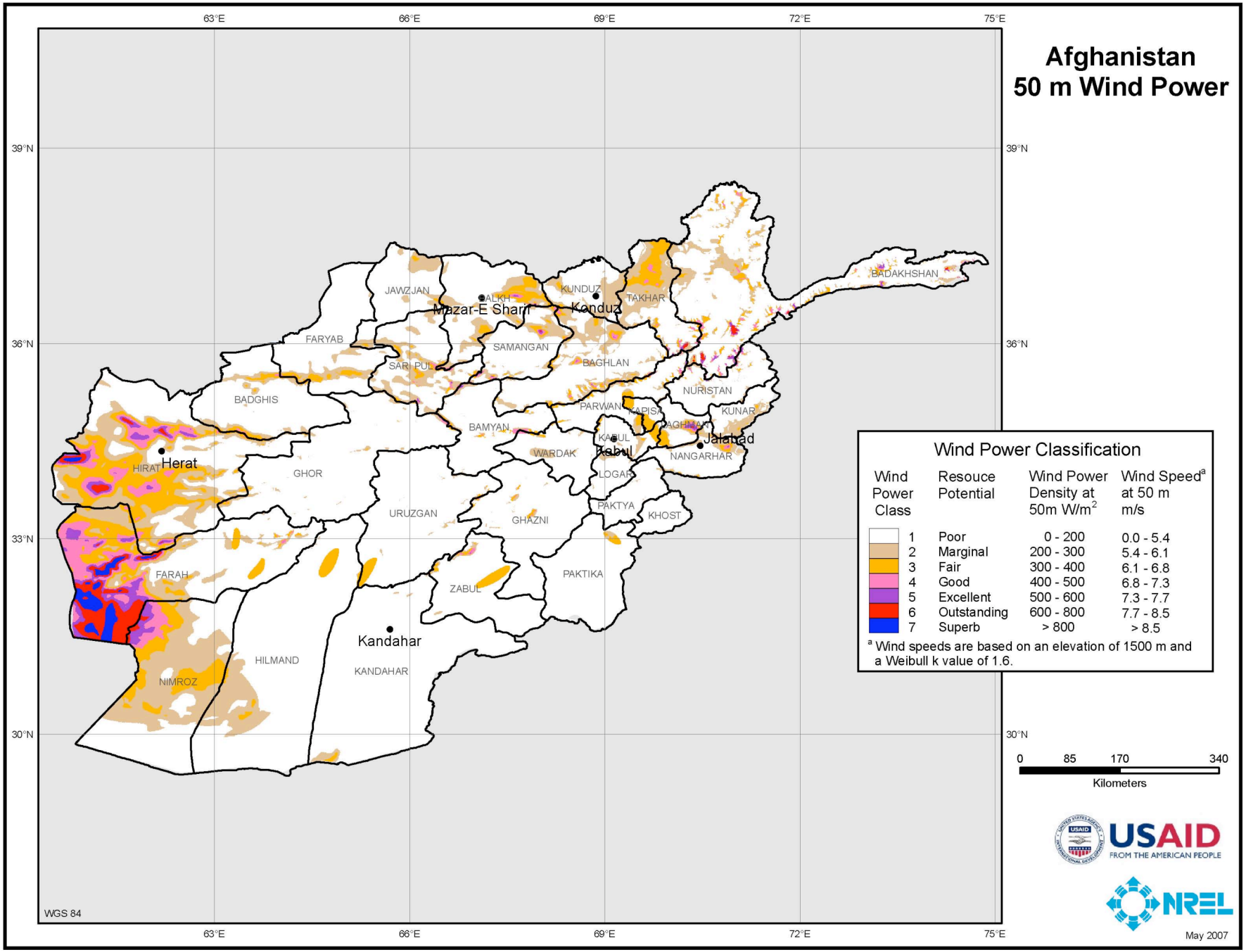




- Wind measurement data from 47 towers in southern Pakistan are being analyzed for the assessment.

Key Deliverables
Afghanistan and Pakistan Wind Mapping

- High resolution annual wind power maps, with documentation, for distribution:
  - estimates for 50-m height above ground
  - horizontal spatial resolution: 1-km grid
- Electronic data sets, including
  - the modified and raw gridded map data in GIS format
  - other products including summaries of processed data from available wind measurement stations
- Presentation of project results to country partners and stakeholders from throughout the region


Afghanistan
50 m Wind Power
63°E
66°E
69°E
72°E
75°E
39°N
36°N
33°N
30°N
JAWZJAN
BALKH
Mazar-E Sharif
KUNDUZ
Konduz
TAKHAR
BADAKHSHAN
FARYAB
SAMANGAN
SAR-I PUL
BAGHLAN
BADGHIS
NURISTAN
PARWAN
KAPISA
KUNAR
LAGHMAN
BAMYAN
KABUL
Kabul
Jalalad
NANGARHAR
WARDAK
HIRAT
Herat
GHOR
LOGAR
URUZGAN
GHAZNI
PAKTYA
KHOST
FARAH
ZABUL
PAKTIKA
Kandahar
HILMAND
KANDAHAR
NIMROZ
WGS 84
Wind Power Classification
Wind Power Class
Resouce Potential
Wind Power Density at 50m W/m2
Wind Speed[a] at 50 m m/s
1 Poor 0 - 200 0.0 - 5.4
2 Marginal 200 - 300 5.4 - 6.1
3 Fair 300 - 400 6.1 - 6.8
4 Good 400 - 500 6.8 - 7.3
5 Excellent 500 - 600 7.3 - 7.7
6 Outstanding 600 - 800 7.7 - 8.5
7 Superb > 800 > 8.5
[a] Wind speeds are based on an elevation of 1500 m and a Weibull k value of 1.6.
0 85 170 340
Kilometers
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Afghanistan's Wind Resources Major Areas

- Major wind resource areas
  - Western Afghanistan especially
    - Northwestern Nimroz
    - Western Farah
    - Western Herat
  - Northeastern areas especially
    - Eastern Balkh
    - Northern Takhar
  - Wind corridor areas including
    - Near Jabalsaraj, Sarobi, and Tirgari in eastern Afghanistan
    - Near Qalat, Gadamsar, Walakhor, Golestan, and Gorzanak in central/southern Afghanistan
  - Elevated mountain summits and ridge crests especially in northern and eastern Afghanistan

AFGHANISTAN - WIND ELECTRIC POTENTIAL

Good-to-Excellent Wind Resource at 50 m (Utility Scale)

Wind Resource Utility Scale	Wind Class	Wind Power W/m^2	Wind Speed m/s	Land Area km^2	Percent Windy Land	Total Capacity Installed MW
Good	4	400 - 500	6.8 – 7.3	15,193	2.4	75,970
Excellent	5	500 - 600	7.3 – 7.7	6,633	1.0	33,160
Excellent	6	600 - 800	7.7 – 8.5	6,615	1.0	33,100
Excellent	7	> 800	> 8.5	3,169	0.5	15,800
Total				31,611	4.9	158,100

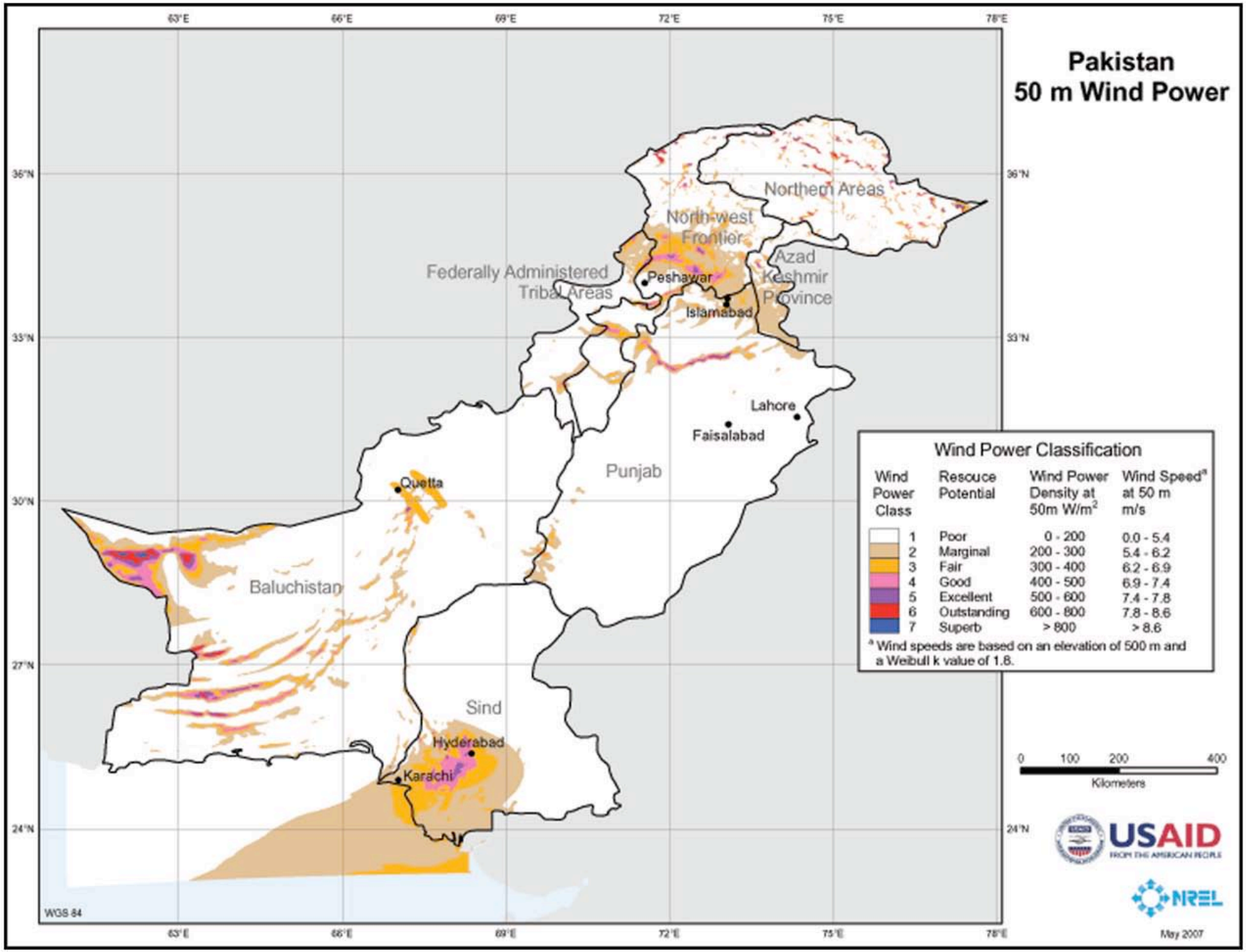
Assumptions

Installed capacity per km^2 = 5 MW

Total land area of Afghanistan = 645,810 km^2

Conclusions for Afghanistan Wind Mapping

- Advanced modeling and analysis techniques employed to produce detailed wind resource maps of Afghanistan
- High resolution wind maps and assessment information
  - Useful to identify best prospective areas and screen out less promising areas, minimizing cost and time of prospecting
  - Does not eliminate the need for on-site wind measurement
- Windy land area and theoretical wind potential estimates
  - Class 4+ (good-to-excellent for utility-scale applications)
    - 31,600 sq km, almost 5% of Afghanistan's total land area (650,000 sq km)
    - 158,000 MW of potential installed wind capacity (assumes 5 MW/sq km)
  - Good potential for many wind/diesel and off-grid applications
    - Almost 12% of Afghanistan's land area has Class 3 or better wind resource


Pakistan
50 m Wind Power
63°E
66°E
69°E
72°E
75°E
78°E
36°N
33°N
30°N
27°N
24°N
Northern Areas
North-west Frontier
Federally Administered Tribal Areas
Azad Kashmir
Province
Peshawar
Islamabad
Lahore
Faisalabad
Punjab
Quetta
Baluchistan
Sind
Hyderabad
Karachi
Wind Power Classification
Wind Power Class
Rescuce Potential
Wind Power Density at 50m W/m2
Wind Speed[a] at 50 m m/s
1 Poor 0 - 200 0.0 - 5.4
2 Marginal 200 - 300 5.4 - 6.2
3 Fair 300 - 400 6.2 - 6.9
4 Good 400 - 500 6.9 - 7.4
5 Excellent 500 - 600 7.4 - 7.8
6 Outstanding 600 - 800 7.8 - 8.6
7 Superb > 800 > 8.6
[a] Wind speeds are based on an elevation of 500 m and a Weibull k value of 1.8.
0 100 200 400
Kilometers
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NREL
WGS 84
May 2007

Pakistan's Wind Resources
Major Areas

- Major wind resource areas
  - Southeastern Pakistan especially
    - Hyderabad to Gharo region in southern Indus Valley
    - Coastal areas south of Karachi
    - Hills and ridges between Karachi and Hyderabad
  - Northern Indus Valley especially
    - Hills and ridges in northern Punjab
    - Ridges and wind corridors near Mardan and Islamabad
  - Southwestern Pakistan especially
    - Near Nokkundi and hills and ridges in the Chagai area
    - Makran area hills and ridges
  - Central Pakistan especially
    - Wind corridors and ridges near Quetta
    - Hills near Gendari
  - Elevated mountain summits and ridge crests especially in northern Pakistan

PAKISTAN - WIND ELECTRIC POTENTIAL

Good-to-Excellent Wind Resource at 50 m (Utility Scale)

Wind Resource Utility Scale	Wind Class	Wind Power W/m^2	Wind Speed m/s	Land Area km^2	Percent Windy Land	Total Capacity Installed MW
Good	4	400 - 500	6.9 – 7.4	18,106	2.1	90,530
Excellent	5	500 - 600	7.4 – 7.8	5,218	0.6	26,090
Excellent	6	600 - 800	7.8 – 8.6	2,495	0.3	12,480
Excellent	7	> 800	> 8.6	543	0.1	2,720
Total				26,362	3.0	131,800

Assumptions

Installed capacity per km^2 = 5 MW

Total land area of Pakistan = 877,525 km^2

Only land area included in calculations

Conclusions for Pakistan Wind Mapping

- Advanced modeling and analysis techniques employed to produce detailed wind resource maps of Pakistan
- High resolution wind maps and assessment information
  - Useful to identify best prospective areas and screen out less promising areas, minimizing cost and time of prospecting
  - Does not eliminate the need for on-site wind measurement
- Windy land area and theoretical wind potential estimates
  - Class 4+ (good-to-excellent for utility-scale applications)
    - 26,400 sq km, about 3% of Pakistan's total land area (800,000 sq km)
    - 132,000 MW of potential installed wind capacity (assumes 5 MW/sq km)
  - Good potential for many wind/diesel and off-grid applications
    - Almost 9% of Pakistan's land area has Class 3 or better wind resource